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UNITED STATES
DEPARTMENT OF THE INTERIOR
J. A. KRUG, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

INFORMATION CIRCULAR

HOME INSULATION WITH MINERAL PRODUCTS --

CONSERVES FUEL - REDUCES COST - INCREASES COMFORT

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BY

OLIVER BOWLES

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

HOME INSULATION WITH MINERAL PRODUCTS - CONSERVES FUEL - REDUCES COST - INCREASES COMFORT[1]

By Oliver Bowles[2]

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INTRODUCTION

The conservation of fuel became a critical problem during the recent war, particularly in the East. Fuel-oil supplies were short, the demands for coal increased, and householders were called upon to reduce the temperatures in their homes. Home owners were urged to employ every means available to reduce fuel consumption, the most important of which was to insulate their dwellings. The Bureau of Mines, United States Department of the Interior, took steps to promote the conservation of fuel by issuing a report[3] on home insulation which has been widely circulated. The American populace

1/ The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7388."

2/ Chief, Nonmetal Economics Division, Bureau of Mines.

3/ Bowles, Oliver, Home Insulation with Mineral Products - Conservation of Fuel for War: Bureau of Mines Inf. Circ. 7220, 1942, 11 pp.

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responded patriotically to the requests of various Government agencies for voluntary conservation of fuels; they accepted cheerfully the restrictions imposed, the crisis was weathered, and with termination of hostilities the unhappy situation was relieved.

Fuel conservation, however, is not merely a war emergency problem; it is a continuous, ever present issue. Coal and petroleum resources are irreplacable assets, and when fuel is burned it is exhausted - there is no scrap recovery. Fortunately, the United States has been richly endowed with mineral fuels; but population is growing, industrial demands for fuel are increasing, and mines and oil wells are becoming deeper and more costly to operate. For the sake of generations to come all national resources, particularly irreplaceable fuels, should be conserved.

A long step in the direction of fuel conservation is the general recognition that insulation is an essential element of dwelling construction. Fortunately, when the home owner takes measures to conserve fuel, he is not called upon to make purely unselfish (altruistic) sacrifices to advance the general welfare; he has the added incentives of saving money and promoting more comfortable living in his own home.

THE HEATING PLANT AND ITS OPERATION

The furnace is the first point where fuel economy may be sought. Each furnace is designed for a particular type and grade of fuel. Certain heating plants function best on fuel oil; others on select sizes and types of coal. Unless the proper fuel is used, improper combustion ensues, and heating efficiency declines. By careful study each home owner should learn to care for his heating plant and operate it efficiently. For practical advice on domestic heating problems the reader is referred to Bureau of Mines Information Circular 7229, How to Save Fuel at Home, by J. F. Barkley; copies may be obtained on request from the Bureau of Mines.

INSULATION AS AN AID IN CONSERVING FUEL

Weatherstripping, storm windows, and storm doors are widely recognized as important means for conserving heat. Wall, floor, ceiling, or roof insulation are more essential if maximum results are to be attained, because greater heat-loss areas are involved. The actual saving of fuel that may be accomplished by insulation is discussed later. Common insulating materials are mineral wool (a term which in its broader sense includes rock wool, slag wool, and glass wool), vermiculite, asbestos, diatomite, pumice and other porous rocks or earths, magnesia, aluminum foil, sawdust, vegetable and wood fibers in various forms, insulating boards made of vegetable or mineral products, animal hair, and cork. These materials may be placed in the hollow spaces of walls, between studding or furring strips, between ceiling or floor joists, or between roof rafters. In this report consideration is given only to those materials that are of mineral origin.

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SUPPLEMENTARY BENEFITS OF INSULATION

Aside from the conservation of fuel resources, which is of ultimate benefit to everyone, insulation has certain definite advantages to the householder, as follows:

Health and Comfort

By reducing heat transfer through walls, ceilings, and floors in winter insulation raises the inside wall and ceiling surface temperatures in a heated house to such an extent that the falling currents of air (drafts) resulting from warm air coming in contact with chilled surfaces are noticeably diminished. Thus, all areas of living quarters become comfortable for the occupants, and the danger of colds brought on by drafty conditions is reduced. The same barrier will bring about indoor summer comfort. Heat is present in every object that we touch or see and can be defined as that form of energy which flows from one body to another by virtue of a difference in temperature between the two bodies. Thus, the walls and roof of a house, exposed to the direct radiant heat of the sun, begin to deliver this heat to the interior. Insulation retards this process and thus reduces indoor summer temperatures.

Dollar Savings

As pointed out in a later section of this report devoted to Fuel Saving Accomplished by Insulation nearly a billion dollars could be saved each year in existing dwellings of the United States by fuel-conservation measures (including insulation, storm windows and doors, weather stripping, caulking, and other means). Such enormous savings would substantially reduce the fuel budget of innumerable householders. A newer source of heat for homes not mentioned before is electricity which has definite possibilities. It is especially dependent upon insulation and all other heat-saving measures for economical performance.

Fire Protection

Incombustible heat-insulating barriers in roofs and walls make even frame buildings slow-burning, and this advantage has been recognized in the fire-prevention codes of many cities. The George Washington home, Mount Vernon, was insulated upon the recommendation of the National Bureau of Standards, because mineral wool placed between rafters and in the walls around dormer windows would inhibit the spread of fire. Tests at the National Bureau of Standards showed that a wood-lath partition filled with mineral wool would stop the passage of fire for 1 hour, at the end of which time the studs were still able to carry the load. Photographs of burned houses have illustrated the fact that flames, originating in the attic space from lightning, defective flues, or crossed wiring, have been checked at the line where the mineral wool lay between the joists of the second floor ceiling until the arrival of the fire department saved the balance of the house.

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Reduced Redecoration Expense

The decrease in drafts within the rooms of an insulated house reduces the play of particles of dirt and dust upon walls and ceilings, and the more even temperatures of room-side surfaces, resulting from the limitation of heat escape (thermal transfer), make unlikely the appearance of disfiguring lath and beam marks. The life-expectancy of all types of interior decoration is thus increased, and redecoration becomes necessary less frequently.

Increased Resale Value

There is such a widespread demand for insulated houses as living quarters that in the event of resale an insulated house is more easily marketed. The insulated house is also a better mortgage risk for the lender since the borrower's cash position is improved by decreased fuel expenditures and because of the less frequent need for redecoration.

PERFORMANCE OF INSULATION

Insulation reduces the transfer of heat units from one side to the other of the insulating medium, irrespective of the side on which the heat is generated. In winter it reduces the escape of heat produced by fuel combustion on the inside; and in summer, in reverse action, it reduces the penetration of the radiant energy of the sun. The result is to increase human comfort both in summer and winter.

Heat is transferred in three ways - by conduction, convection, and radiation. Insulation affects each means of transfer.

Conduction is the flow of heat through a solid, such as the heat from boiling water passing along the handle of a silver spoon. So, in lesser degree, the heat generated inside or outside a room flows through walls, ceilings, and floors. When a barrier of insulation is interposed, the flow diminishes.

Convection is a transfer of heat by moving currents of air. As such currents move past a warm surface they pick up the heat and carry it with them. Although hollow spaces in walls may be partly sealed, a difference in temperature between top and bottom of the sealed areas creates currents of air, which always carry heat from the warmer side to the colder.

Radiation is the process by which the sun's energy is carried to the earth. Any warmer surface transfers heat by radiation to any cooler neighboring surface. This radiant transfer even takes place within a room and between the walls of a room; thus the warmer walls of a house radiate heat to the colder ones. The human body also radiates heat. When this radiation is too rapid due to the low temperature of surrounding objects, personal discomfort and chills will result at ordinary room air temperature. When walls and other surroundings are at a reasonable temperature, comfort will ordinarily ensue under the same air-temperature conditions.

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Units of Heat

To measure the extent of heat transfer the British thermal unit is used: 1 B.t.u. is required to raise 1 pound of water 1° F. under specified conditions (from 39° to 40° F. at sea level). Heat losses are measured in British thermal units per square foot of material 1 inch thick per hour per degree Fahrenheit temperature difference. This quantity is sometimes called the k-factor; and, as it is the measure of heat loss, the smaller this constant is for a given material the better the insulating properties of the material.

The following table shows the thermal conductivity of a variety of materials, many of which are used in home construction. As indicated in this table the thermal conductivity or k-factor of most light, fibrous, or porous materials sold primarily as insulators ranges from 0.25 to 0.50 B.t.u. per hour.

Thermal conductivity of various materials[1]

Material tested	Density, lb. per cu. ft.	Conductivity[2] (mean temp. 90° F.)
Sealed hollow spaces:		
Air space - walls (3-1/2 in.)	0.081	0.86 to 1.10
Animal and vegetable insulations:		
Cork, ground	8.1	.27 to .31
Cotton	.85	.29
Flax fiber	13.0	.31 to .33
Hair felt	13.0	.26
Pine wood	34.3	.8 to 1.00
Pure wool	6.24	.26 to .32
Silk	6.24	.28 to .34
Sugarcane fibers	13.5	.34
Wood-pulp board, plaster base	16.2	.3 to .4
Mineral insulations:		
Diatomite powder	10.6	.3 to .5
Diatomite blocks	28.1	.58
Expanded vermiculite	7 to 10	.38 to .48
Magnesia (85 percent magnesia, 15 percent asbestos)	13 to 16	.40 to .46
Mineral wool	2 to 7	.27 to .30
Pumice gravel	18.8	.64
Structural materials:		
Bricks, dry	125.0	3.0 to 6.0
Brickwork (mortar bond)	132.0	4.0 to 5.0
Building stone	165.0	12.5
Concrete, 1-2-4	150.0	5.0 to 9.0
Glass, plate	15.5	3.6 to 7.3
Gypsum plaster	46.2	2.0 to 5.0
Slate shingles	162 to 205	10.0 to 10.4
Steel, 1 percent carbon	489.0	314.0 to 328.0
Tile (clay and plaster)	12.7	.60

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Thermal conductivity of various materials1/ (Cont'd)

Material tested	Density, lb. per cu. ft.	Conductivity2/ (mean temp. 90° F.)
Pure metals:		
Copper	558.0	2,580.0 to 2,670.0
Silver (greatest conductivity)	655.0	2,860.0 to 2,920.0

1/ Authorities: National Bureau of Standards, Federal Housing Administration, and university and research laboratories.

2/ Conductivity: British thermal units transmitted per hour per square foot of material 1 inch thick, per degree Fahrenheit difference in temperature of the 2 faces.

Heating requirements are measured by engineers in degree-days. The heating season is the United States is, roughly, October 1 to May 1, but it varies greatly in different parts of the country. Degree-days, however, are published in heating handbooks and in the United States Weather Bureau reports for nearly every city in the United States and Canada. They are based upon mean-temperature data. One degree below 65° F. for a 24-hour period equals 1 degree-day. The assumption is that no artificial heat is required when the mean daily outside temperature is 65° F.

SAVING ACCOMPLISHED BY INSULATION

Enormous quantities of fuel are used for heating buildings. The following data for the United States for 1944 have been compiled by the Anthracite and Coke Section of the Bureau of Mines Coal Economics Division from various sources. The total anthracite used for space-heating purposes was approximately 45,000,000 net tons. The quantity of bituminous coal, lignite, and fuel briquets so used is somewhat uncertain but was about 82,000,000 net tons. Coke for space heating amounted to about 7,000,000 net tons, and fuel oil so used aggregated 200,000,000 barrels. The total value of these products at the point of origin was approximately $940,000,00 The price paid by consumers, including transportation charges and retailers' expenses and profits, was roughly $2,175,000,000. The quantity of gas used for space heating is not available but is known to be considerable and would add materially to the above figures. This prodigious figure for keeping people warm indicates the enormous potential field for saving when economies are introduced.

The National Bureau of Standards demonstrated (T.I.B.M. 15, May 18, 1936) that frame construction, with wood shingles over building paper 3/4-inch wood sheathing outside, and 3/4-inch plaster and metal lath (or 1/2-inch plasterboard or wallboard alone) inside, had an insulating value4/ of 4.6 when the 3-5/8-inch air space was unfilled. When this space was filled

4/ The unit in these tests was the number of hours required for passage of 1 B.t.u. of heat through 1 square foot of wall area per 1° F. temperature difference between air on one side to air on other side.

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with mineral wool the value rose to 16.0. Corresponding figures for a 4-inch brick-veneer wall over the same paper and sheathing and the same interior wall finish were 3.7 when the air space was unfilled and 15.1 when it was filled (T.I.B.M. 14).

Another interesting Bureau of Standards tabulation (T.I.B.M. 3 March 4, 1936) estimates fuel savings up to 40 percent due to the application of simple heat-loss preventives to walls and roof of an unprotected house, and with suitable weatherstripping and storm sash applied to doors and windows the total savings were boosted to 60 percent.

To judge the saving that may be achieved with insulation, reference may be made to a Canadian report5/ embodying the results of a study made on the distribution of heat losses in homes. The study was made on 200 average homes of wood-frame construction, uninsulated, and without weatherstripping or storm windows or doors. It was found that of the heat lost, 16.2 percent was lost through the roof, 27.0 percent through the walls, 25.8 percent through the glass, 24.6 percent by air infiltration, 4.3 percent through the door, and 2.1 percent through other sources, including the floor. When 2 inches of insulating material was applied to the walls of these houses, the heat loss was reduced 17.4 percent; and the addition of 2 inches of insulation to the second-floor ceiling brought about a further reduction of 13.3 percent. Thus, complete insulation saved 30.7 percent of the heat loss.

Heat conservation and fuel saving go hand in hand. The actual quantities of fuel that may be saved by insulation are under constant study by technical schools and colleges. While there is some variation in the results of different tests, the savings obtained are always remarkably large. One of the most complete and dependable studies is that conducted by the Engineering Experiment Station, University of Illinois, on a three-story residence of standard frame construction in Urbana, Ill. Both ceiling and walls of the house were insulated with mineral-wool batts wherever they could be applied conveniently, and in other places nodulated mineral wool having a density of about 5 pounds per cubic foot was blown into place. The results of the tests, which have been described in detail,6/ indicate that insulation produced an average saving of approximately 30 percent in consumption of fuel. This figure agrees closely with the 30.7 percent of heat loss saved by insulation given in the Canadian report to which reference has been made. Another series of tests made by the Tennessee Valley Authority on two identical houses, one insulated with 3-5/8-inch mineral wool and the other without that insulation, revealed a heat-saving differential in the insulated house of 44.75 percent.

5/ Babbitt, J. D., and Hyland, John J., House Insulation in Its Relation to Canada's War Effort: Document N.R.C. 1055, National Research Council of Canada and National Housing Administration, Department of Finance, Ottawa, Canada, 1942.

6/ Kratz, A. P., and Konzo, S., Effect of Insulation on Plant Performance in the Research Residence: Heat., Pip., and Air Cond., May 1941, pp. 318-324.

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To determine exactly the amount of national fuel saving potentially obtainable as of a given period is impossible. Many, if not most, of the homes recently built are completely or partly insulated, and vast numbers of existing homes have been insulated by blowing the insulating medium into walls and between joists and rafters. However, in the millions of homes still lacking insulation, great economies in fuel consumption can be achieved

HOW TO INSULATE

Choice of insulating materials depends largely on relative availability and cost. Generally, mineral products are preferable because of their resistance to fire, electrical short circuits, moisture, termites, vermin, and decay. In new-home construction, if the home owner employs a competent and responsible insulation applicator he may expect to have the insulating done properly. The application of insulation to existing homes requires adequate equipment and special skill. No job is better than the man who installs it. It is important that all open spaces in ceilings and walls be completely filled with the insulating medium. If barriers prevent movement of the fill material, a new opening should be made beyond the barrier. Obviously, leaky roofs and walls should be repaired, so that moisture will not accumulate in the fill. Problems involving the relative merits of various insulating materials and their proper application are not within the province of the Bureau of Mines. The National Bureau of Standards has conducted many studies on insulating problems, and various insulating firms have developed knowledge and skill in application.

MINERAL INSULATION MATERIALS

Mineral Wool

Mineral wool consists of fine, interlaced mineral fibers having the appearance of ordinary loose wool. It is a fibrous, intermeshing material composed principally of silicates of calcium and aluminum. Mineral wool is a generic term covering a number of similar products differentiated chiefly by the raw materials from which they are made. "Rock wool" is made from natural rock (a calcareous shale) or from combinations of various natural minerals or rocks, such as limestone and shale. "Slag wool" is made from iron, copper, or lead blast-furnace slag alone or mixed with fluxing materials. "Glass wool" is made from silica sand, soda ash, and limestone with or without scrap glass or other materials.

The first step in making rock wool is to melt the raw materials, consisting of a properly proportioned mixture of alumina, silica, and lime or magnesia, in a cupola furnace. The molten material is then drawn from the bottom of the cupola in a small stream, the flow and temperature of which are regulated carefully. This molten stream is broken up by a steam jet (at 80 to 100 pounds pressure) into minute droplets, which, while still molten, are propelled rapidly through the air. During their cometlike course, fine threads of material form as tails and fall in a fluffy mass on the floor of the wool room. The fibers are then ready for use or for manufacture into mineral-wool products. Molten furnace slag or glass is made into wool by similar processes.

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Mineral wool is marketed in various forms. Loose wool is the raw product as blown and without subsequent treatment. This is the material from which all mineral-wool products are made. Nodulated or granulated wool largely freed from shot is rolled into small pellets, so that it can be blown into place through an air hose. It is used chiefly for insulating houses already built. Increasing quantities of wool are fabricated into soft, flexible quilts reinforced on one or both sides by specially treated paper. The paper surface designed to be placed on the interior side of the structure is vaporproofed. "Batts" are rectangular shapes made from loose wool mixed with suitable binders and cut to the thickness and size demanded by consumers. Batts are usually reinforced by special paper covers in the same way as blankets. They are generally used for insulating houses during construction, being inserted in walls, floors, or roofs between studs, joists, or rafters. Blankets, used frequently for insulation of industrial furnaces, are made of loose wool treated with binders and are of various rectangular shapes and thicknesses, sewed between wire, metal lath, or other confining mediums. Loose wool with suitable binders also is compressed into blocks for use in refrigerator, stove, and furnace insulation and into various shapes for pipe and boiler coverings. Loose wool mixed with bentonite or plastic fire clay and asbestos fiber is efficient as an insulating cement for filling joints between insulating blocks, as plastic insulation for irregularly shaped objects, and for general heat-conservation use.

The following table gives the most recent available statistics of the mineral-wool industry:

Production of mineral wool in the United States, 1943-44, by products

Product	Home insulation		Industrial insulation		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
1943						
Loose wool (sold as such)	62,978	$1,720,375	6,600	$191,584	69,578	$1,911,959
Granulated wool (sold as such)	277,833	10,257,797	6,704	219,975	284,537	10,477,772
Batts	56,737	4,386,006	3,416	659,799	60,153	5,045,805
Rolls	10,117	541,256	65	2,819	10,182	544,075
Felt	6,781	791,781	34,764	5,236,679	41,545	6,028,460
Blocks	453	40,960	11,068	1,900,450	11,521	1,941,410
Boards	-	-	26,003	12,495,640	26,003	12,495,640
Mineral-wool insulating cement	3,432	238,006	18,839	1,230,681	22,271	1,468,687
Blankets	402	68,862	9,111	1,246,908	9,513	1,315,770
Pipe covering	11	1,522	6,875	1,443,969	6,886	1,445,491
Other	4,029	91,024	5,306	904,617	9,335	995,641
Grand total	422,773	18,137,589	128,751	25,533,121	551,524	43,670,710

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Production of mineral wool in the United States, 1943-44, by products (Cont'd)

Product	Home insulation		Industrial insulation		Total	
	Short tons	Value	Short tons	Value	Short tons	Value
1944						
Loose wool (sold as such)	59,787	1,609,235	5,410	188,876	65,197	1,798,111
Granulated wool (sold as such)	308,411	11,344,433	5,178	160,509	313,619	11,504,942
Batts	52,007	3,633,878	7,446	1,203,245	59,453	4,837,123
Rolls	6,394	372,938	565	30,955	6,959	403,893
Felt	4,683	427,393	38,998	5,154,208	43,681	5,581,601
Blocks	-	-	14,633	1,927,618	14,633	1,927,618
Boards	-	-	36,728	24,635,485	36,728	24,635,485
Mineral-wool insulating cement	1,823	135,861	10,695	825,906	12,518	961,767
Blankets	1	148	7,353	1,021,819	7,354	1,021,967
Pipe covering	-	-	5,240	958,692	5,240	958,692
Other	1,344	54,921	1,570	796,676	2,914	851,597
Grand total	434,480	17,578,807	133,816	36,903,989	568,296	54,482,796

Vermiculite

Vermiculite is another important mineral insulating material. It received its name from its peculiar property of expanding and unfolding into wormlike forms when heated. The name is applied to a group of micaceous minerals that generally are alteration products of biotite, phlogopite, and other varieties of mica. The most pronounced characteristic of vermiculite is its extraordinary expansion in heating; the volume may increase up to 16 times the original. The porous nature of the expanded mineral makes it an excellent heat insulator. It is mined chiefly in Montana, but also in Colorado, North Carolina, South Carolina, and Wyoming, and is processed in plants at various strategic points in the United States. It takes the form of feather-light, resilient pellets, which, when screened or sized to remove particles that are too large or too small, are used as loose fill. Insulating cements made from expanded vermiculite screenings and bentonite or other binder are manufactured by several firms, and at least one manufacturer has produced a compressed vermiculite wallboard. Plaster and concrete, in which vermiculite takes the place of sand or other aggregate, are being used in rapidly increasing quantities; in addition to their heat-insulating value, they have acoustic properties and are light in weight. Vermiculite precast-concrete slabs for roof, floor, or wall construction weigh as little as 25 pounds per cubic foot and are easy to install. If necessary, they can be sawed, cut with a knife, drilled, or nailed in much the same way as wood lumber. Tests by the Underwriters Laboratories, Inc., indicate that vermiculite plasters are effective in preventing the spread of fire from one part of a building to another.

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Production of vermiculite in the United States during recent years is indicated in the following table. The values given in the third column for the exfoliated product are based on the assumptions of an average value of $75 a ton, f.o.b. works, and a 10-percent loss during the exfoliation process.

Screened and cleaned vermiculite sold or used by producers in the United States, 1940-45

Year	Short tons	Value, screened and cleaned	Value, exfoliated
1940.....	22,299	$137,698	$1,505,000
1941.....	23,438	125,444	1,582,000
1942.....	57,848	319,931	3,905,000
1943.....	46,645	471,595	3,149,000
1944.....	54,116	541,744	3,653,000
1945.....	64,808	648,077	4,375,000

Other Mineral Insulators

Diatomite, pumice, and other porous rocks or earths have been used for wall insulation; and diatomite, asbestos, and magnesia (chiefly a mixture of 85 percent technical carbonate and 15 percent asbestos fiber) are used extensively for boiler and pipe coverings.

Aluminum foil is used to increase the value of air spaces by reducing transfer of heat by radiation. Clean metallic surfaces usually are good reflectors of radiant heat, and as much of the transfer of heat across open spaces in buildings takes place by radiation, the use of aluminum on one or both sides of the space may reduce heat losses substantially. Aluminum foil also is applied in crumpled form to be self-spacing.

Stiff, fibrous insulating boards having considerable structural strength usually are not as good insulators as lighter, looser materials. Ordinarily, the lower the density, the better the insulating value.

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